TRACHEAL SOUND ACQUISITION USING LASER DOPPLER VIBROMETER

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1. Introduction

Breathing is vital for human life. Respiratory related diseases cause more than one million deaths annually. Pneumonia annually kills over 1.8 million children throughout the world. The vast majority of these deaths occur in resource poor regions such as the sub-Saharan Africa and remote Asia. Prompt diagnosis and proper treatment are essential to prevent these unnecessary deaths [1,2]. The sound of breathing activity can be used to assess the state of the lungs and detect adverse problems involving respiratory failure (respiratory auscultation). Clinical practitioners use mechanical stethoscopes to listen to breathe sounds and analyse sounds they hear. Their analysis is based on their own observation, experience, and auditory capabilities. This procedure is subjective, time consuming and not always accurate and does not lend itself to a quantitative analysis of the sounds heard from the patients [3]. Computerised monitoring of breathing activity has overcome some limitations of subjective human observation and inconsistency of stethoscope contact [4,5,6].

Traditionally, stethoscopes are used for respiratory auscultation to analyse the lung sounds. They are unreliable for assessing respiratory sounds in people, especially in infants. This has important implications for their use as diagnostic tools for lung disorders in infants, and confirms that stethoscopes cannot be used as the gold standard [7]. Because of the unreliability of the stethoscope, the validity of acoustic analysis cannot be demonstrated, in principle it could discriminate between sounds well and has shown good within-observer reliability. The amplitude variations of spectral components of lung sound signals is sufficient to have sensitivity to the louder sounds produced by breathing. The further development of smart pattern recognition systems may improve the reliability of acoustic observations so that it can be used in clinical practice [8,9,10].

The aim of this work is to investigate the reliability of mechanical stethoscopes to detect tracheal sounds. Five stethoscopes are calibrated using a shaker system and the Head And Torso Simulator (HATS). Measurements are carried out on three human subjects to record their tracheal sounds. The results are compared with the data obtained from three human subjects using laser Doppler vibrometer which is a non-contact technique.

2. MEASUREMENT PROCEDURE

Measurements were carried out on three human subjects to detect tracheal sounds in a hemi anechoic chamber as shown in Figure 1. Two tracheal sound recording techniques were used for experiments. Firstly, five mechanical stethoscopes (Red Stethoscope, 3M Littmann Classic II S.E. Teaching, KT-102 Rapapport, 3M Littmann Select, and Littman Classic III) were tested and calibrated using shaker system and the Head And Torso Simulator (HATS) as shown in Figure 2. Large diaphragm of stethoscope was placed on anterior cervical triangle of three volunteers. The stethoscope earbuds were placed in the anterior notch of the outer ear of the HATS. The breathing activity of three human subjects was recorded for 10 seconds when participant was inhaling and exhaling. The procedure was repeated for five mechanical stethoscopes on three human subjects. The 100 mm thick sound absorptive material was placed in between the participant and HATS to attenuate breathe sounds.

Figure 1: Measurement set-up for laser Doppler vibrometer

Figure 2: Measurement set-up for shaker system and the Head And Torso Simulator (HATS)

Secondly a laser Doppler Vibrometer was used to record tracheal sounds on three participants. The recorded tracheal sounds shown in Figure 3 was processed using Adobe Audition CC 2015. The Noise Print of unwanted audio data was captured and then eliminated using Noise Reduction (process). The unwanted noise appeared due to laser interaction with throat of the participants were removed. Moreover, clicks and pops artefacts were "cleaned" by the Click/Pop Eliminator. Parameters for each noise removal tool were adjusted individually in order to obtain the cleanest signal possible as shown in Figure 4.

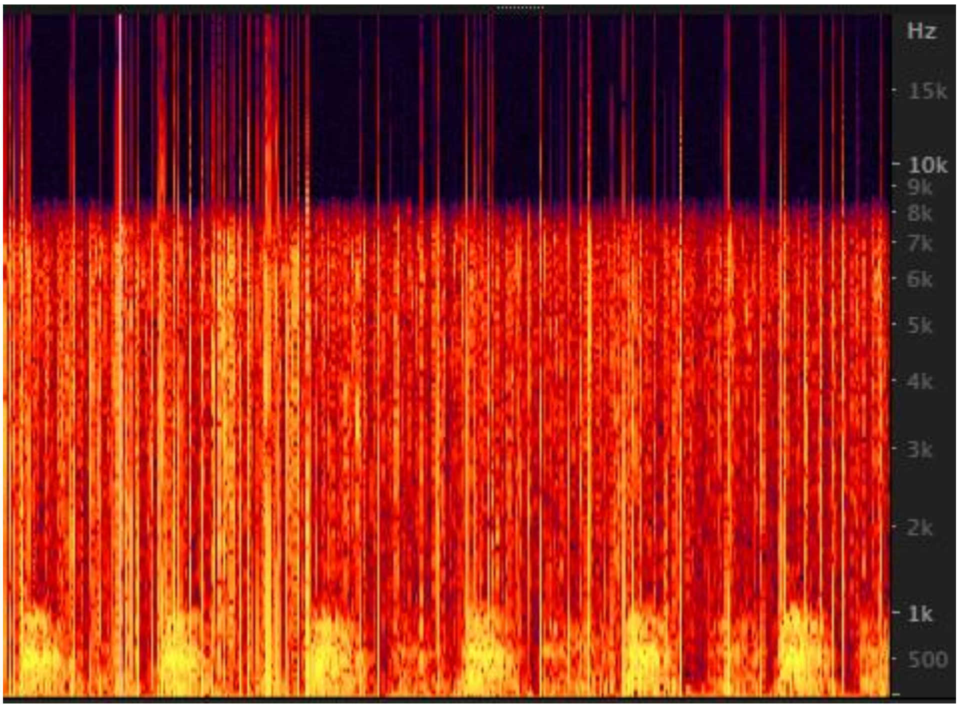

Figure 3: The frequency spectrum of the initial recorded audio signal.

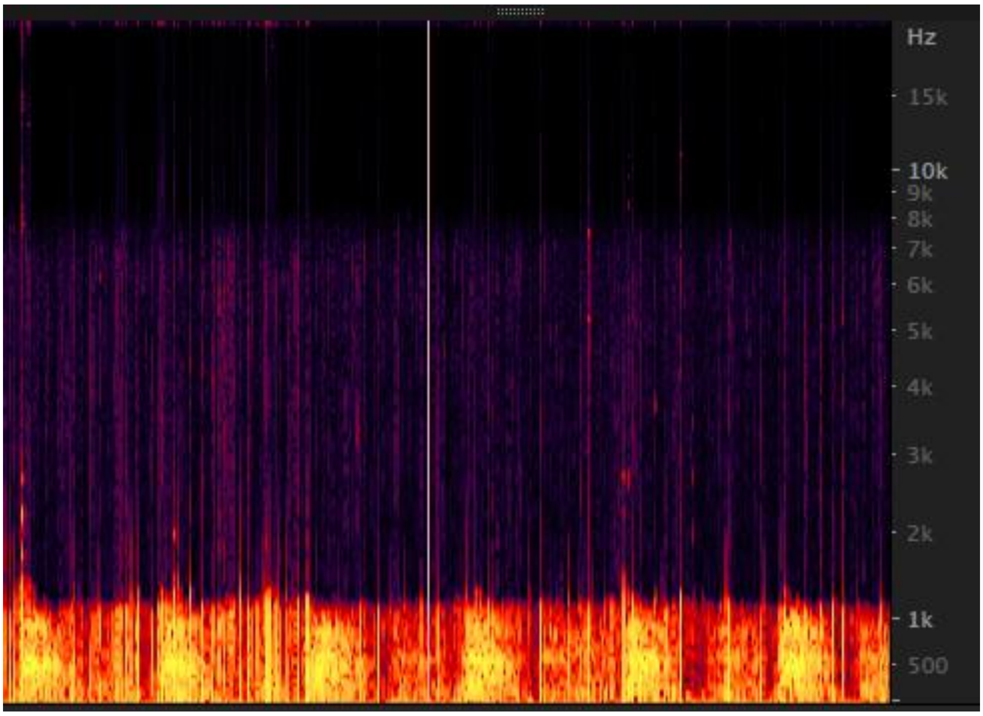

Figure 4: The frequency spectrum of the denoised audio signal.

For acoustical flow estimation purposes, the tracheal respiratory sound signal is preferred because of its high intensity and sensitivity changes in respiratory flow for comparison with lung sounds. Tracheal sounds were detected by using a laser Doppler vibrometer pointed to the trachea of the participant during inhalation and exhalation. The recorded audio signal using laser Doppler vibrometer is given as a function of frequency in Figure 5. Recorded tracheal sound was denoised using Hanning window with a spectrum algorithm in Adobe Audition 2015, a low pas filter (1kHz @ 48 dB/Oct) and pop/click reduction (process) as shown in Figure 6.

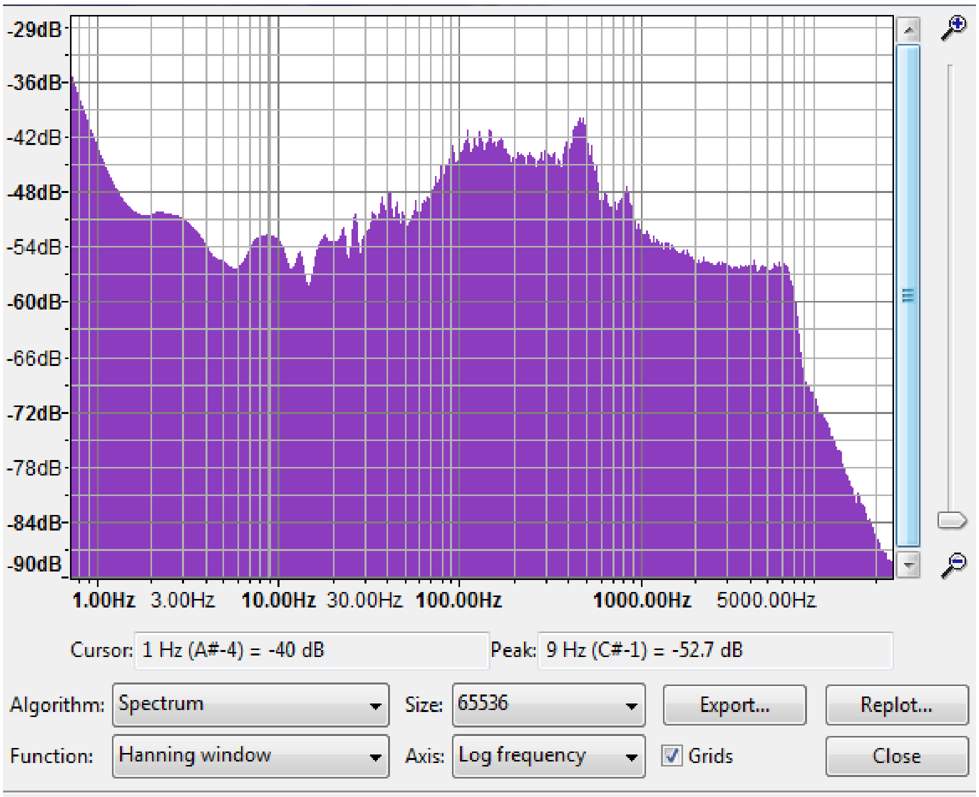

Figure 5: Original frequency spectrum of recorded audio signal.

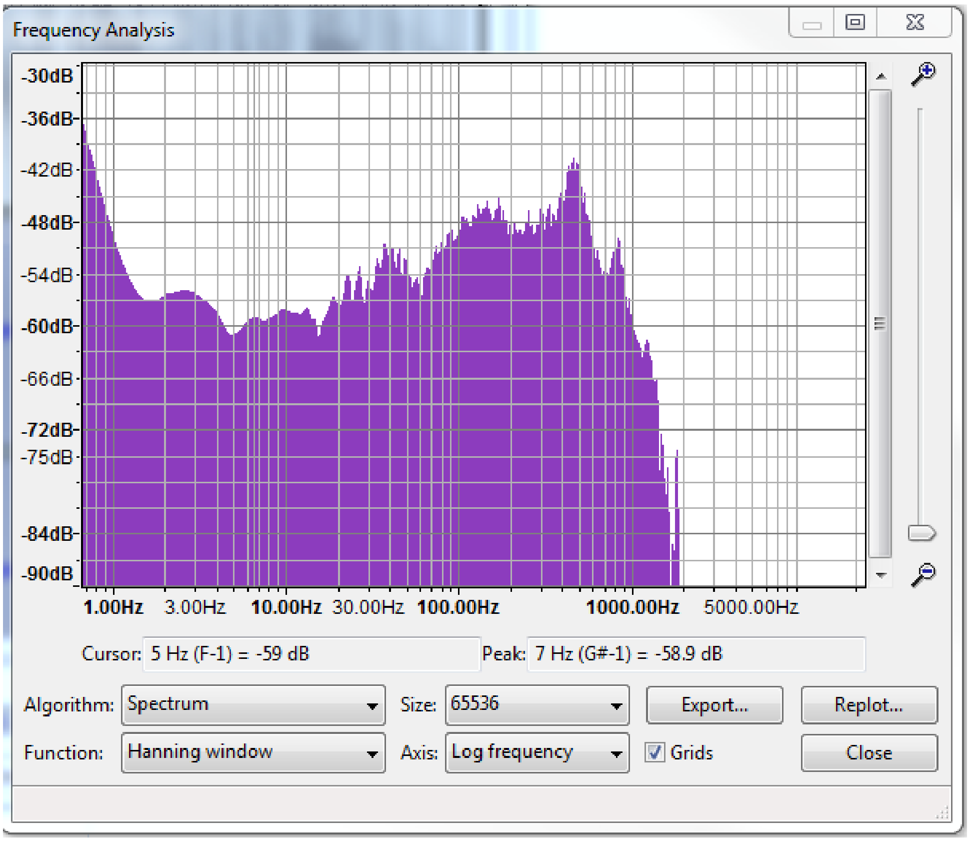

Figure 6: De-noised frequency spectrum of recorded audio signal

3. ANALYSIS OF RESULTS

Stethoscopes background noise were measured using HATS and pink noise. Measured amplitudes of five stethoscopes are similar below 500 Hz with a resonance peak around 100 Hz as shown in Figure 7. The difference between amplitudes of stethoscopes are increasing with frequency above 500 Hz.

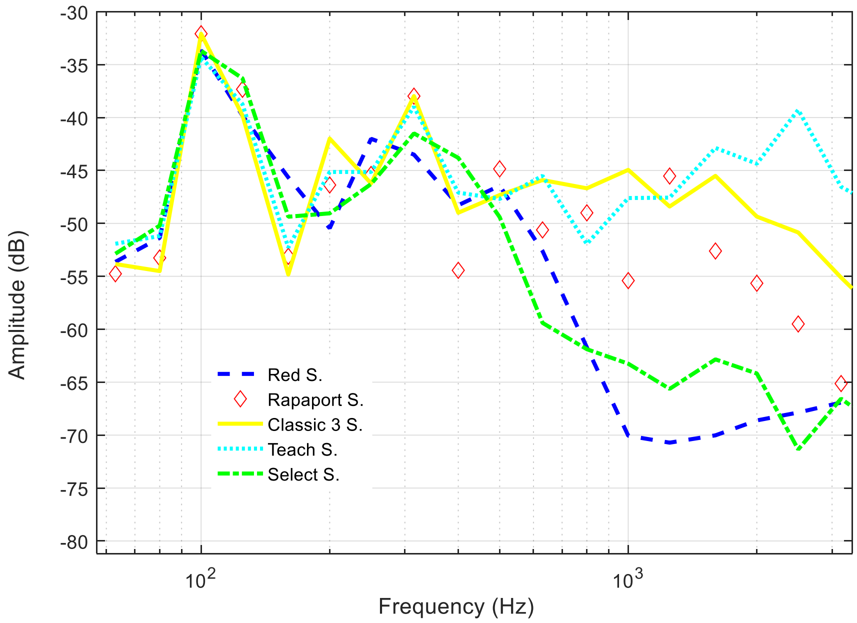

Figure 7: Stethoscopes background noise tests using HATS and pink noise. (Red -->Red Stethoscope, Rapaport-->KT-102 Rapapport stethoscopes, Classic 3 --w> Littman Classic III stethoscopes, Teaching --> 3M Littmann Classic II S.E. Teaching stethoscopes, and Select -- > 3M Littmann Select stethoscopes).

Tracheal sound measured using laser doppler vibrometer is compared with sound detected from three human subjects using five different mechanical stethoscopes. Detected responses from participates 1, 2, and 3 are presented as a function of frequency in Figures 8, 9, and 10 respectfully. Results from five stethoscopes in Figure 8 have similar pattern but different amplitudes. The reasons for discrepancy between results obtained from stethoscopes can be due to different diaphragms and/or characteristics of stethoscopes. Furthermore, it shows that the breath sounds are not repeatable. They might have similar wave pattern, but their amplitudes are different. Laser Doppler vibrometer results are comparable with the one obtained from stethoscopes, especially below 1000 Hz they are in a good agreement. The tracheal sounds measured on participant 2 using laser Doppler vibrometer and stethoscopes are following a similar pattern except for cheap red stethoscope which has higher amplitude below 1000 Hz and laser Doppler vibrometer producing lower amplitude above 1000 Hz as shown in Figure 9. This might be caused by weak breathing performance of human subject. The laser vibrometer and stethoscopes' amplitudes measured on participant 1 and participant 3 are in a better agreement as shown in Figure 8 and Figure 10. Laser Doppler vibrometer performance is comparable with stethoscopes performance below 1000 Hz and it is a promising non-contact technique to measure tracheal sound. The main issue with using laser Doppler vibrometer was to make human subject to stand still during the inhalation and exhalation. The movement of participant is obtained using only X axis, however Y and Z axis movement appears as well, which makes the artefact appearance. The thin sticker, placed on the skin of the participant can help to reduce the laser-hair-skin interaction, and reduce number of click/pop artefacts. Another non-contact solution could be achieved by using video amplification technique, that can transduce video signal into waveform. More expensive method could be done by pointing laser beam into an optic fibre, with other end of the fibre was in contact with skin. This can reduce the artefacts appeared by movements of the participant.

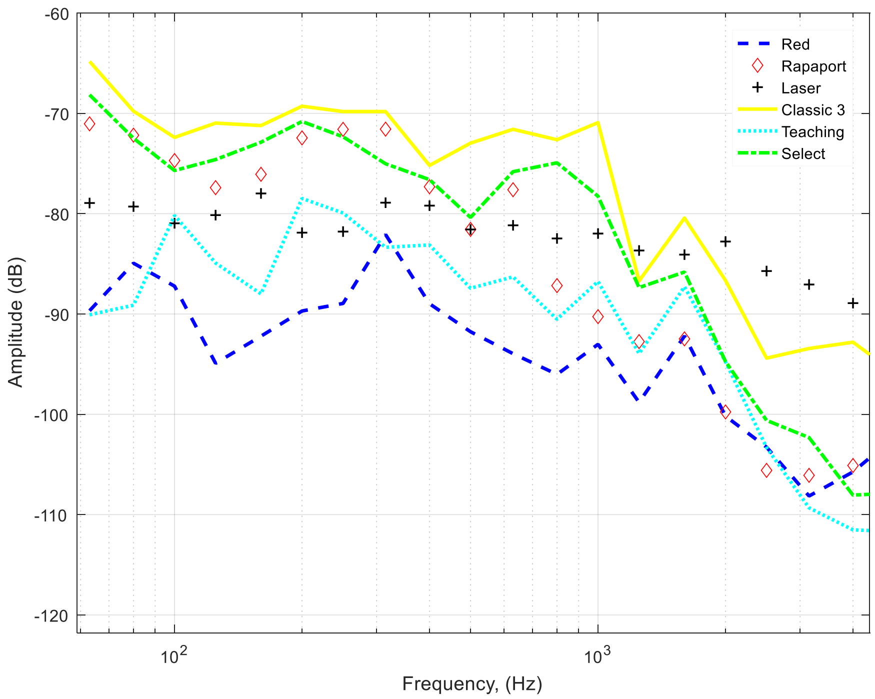

Figure 8. Amplitude of stethoscopes given as a function of frequency for participant 1. (Red -->Red Stethoscope, Rapaport-->KT-102 Rapapport stethoscopes, laser -->laser Doppler vibrometer, Classic 3 -- > Littman Classic III stethoscopes, Teaching --> 3M Littmann Classic II S.E. Teaching stethoscopes, and Select -- > 3M Littmann Select stethoscopes).

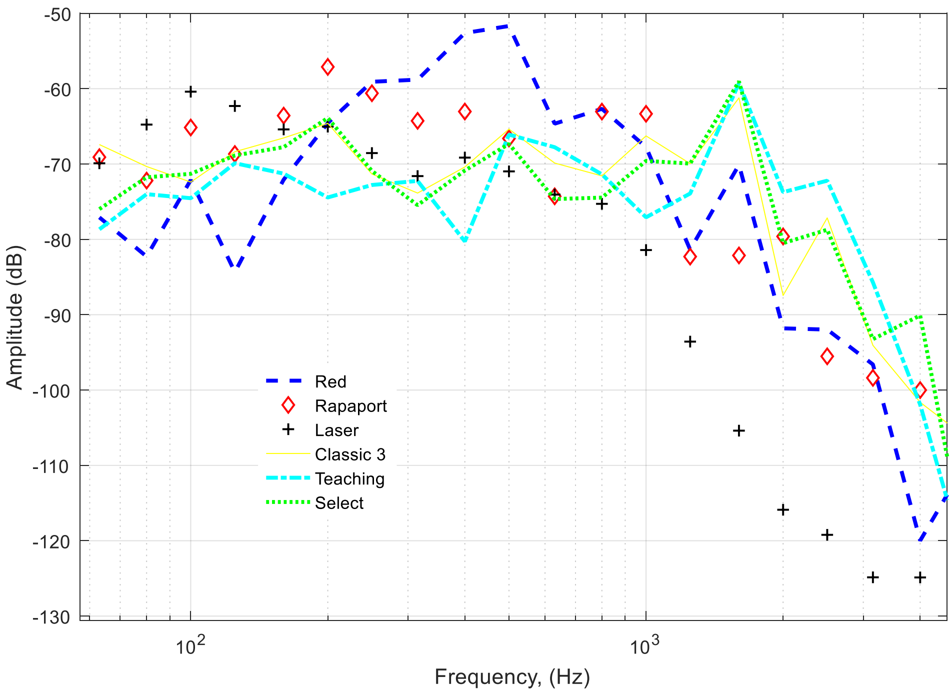

Figure 9. Amplitude of stethoscopes given as a function of frequency for participant 2. (Red -->Red Stethoscope, Rapaport-->KT-102 Rapapport stethoscopes, laser -->laser Doppler vibrometer, Classic 3 -- > Littman Classic III stethoscopes, Teaching --> 3M Littmann Classic II S.E. Teaching stethoscopes, and Select -- > 3M Littmann Select stethoscopes).

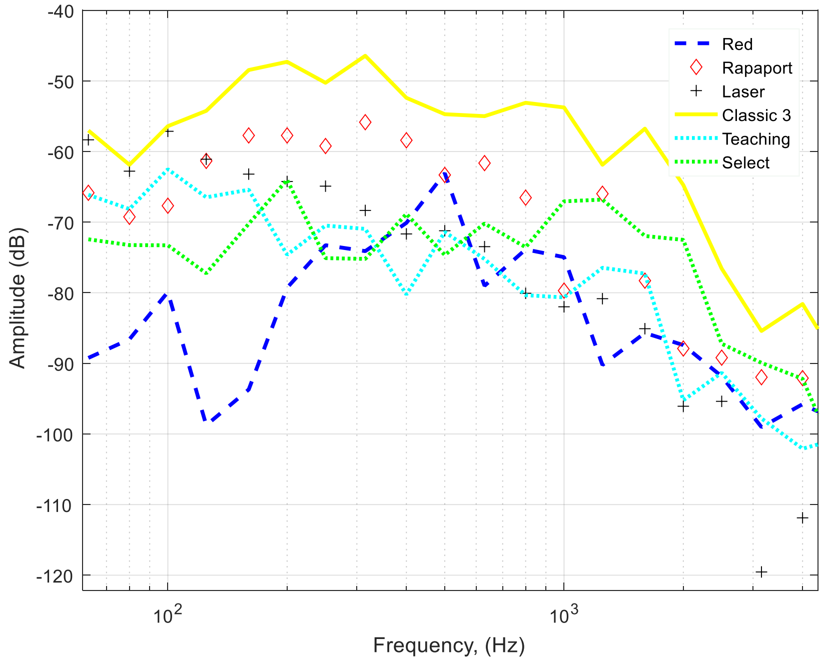

Figure 10. Amplitude of stethoscopes given as a function of frequency for participant 3. (Red -->Red Stethoscope, Rapaport-->KT-102 Rapapport stethoscopes, laser -->laser Doppler vibrometer, Classic 3 -- > Littman Classic III stethoscopes, Teaching --> 3M Littmann Classic II S.E. Teaching stethoscopes, and Select -- > 3M Littmann Select stethoscopes).

4. CONCLUSION AND FURTHER WORK

An experimental investigation was carried out to analysis tracheal sounds detected using stethoscopes and a laser Doppler vibrometer. The results show that mechanical stethoscopes are not reliable tools to detect lungs sounds. The sounds detected with stethoscopes are different in terms of amplitude and wave shape at high frequencies. Clinical practitioners' analysis of lung sounds are limited to their experience and auditory capabilities. Laser Doppler vibrometer is a new and non-contact technique to detect lung sounds but it needs to be improved and it is an expensive tool to use.

There is a need for low-cost, small, and non-contact smart devices to provide clinical practitioner with much more detailed information than traditional stethoscopes without the need for cumbersome and expensive sensor deployment. We aim to develop a smartphone-based system to detect and analyse the complex lung sounds with the aim of early diagnosis of respiratory disease. So early diagnosis of the condition could significantly reduce the overall long-term treatment costs by reducing admissions to hospital. The low anticipated costs of such a smartphone system should enable increased overall take up of this system by clinics compared to other technologies [11-15].

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